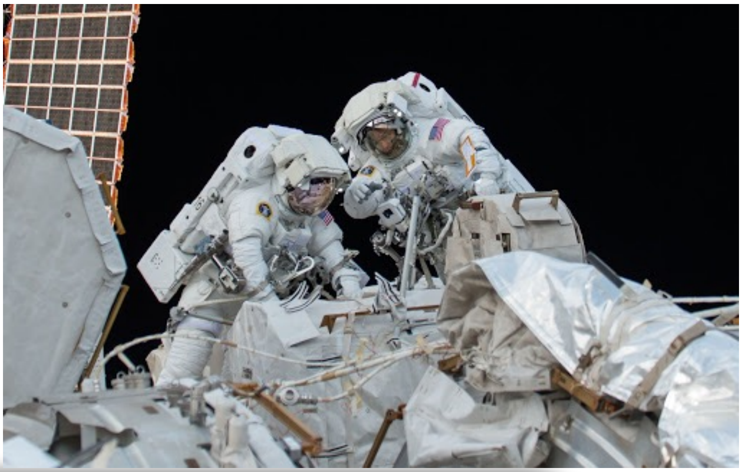
Executive Summary

Over the course of an extravehicular activity (EVA), the crew, equipment, and mission are all exposed to extraordinary risks. Tools can be damaged or lost, mission objectives can fail, and astronauts can suffer a wide range of injuries, from minor cuts and bruises to thermal burns. The astronauts' lives depend on a long list of hardware and procedures operating as intended; if anything goes wrong the crew might not survive. EVA mishaps typically fall under three categories (or some combination thereof): hardware failures—where a tool or system does not perform its intended task, hardware damage, or missteps taken by the crew/mission control. Special considerations must be taken so that all the equipment used by the crew can withstand the rigors of the EVA tasks, and that the operations required of the crew do not put them at unnecessary increased risk.

Relevant Standards

NASA-STD-3001 Volume 1, Rev B
[V1 4014] Completion of Critical Tasks

NASA-STD-3001 Volume 2, Rev C
[V2 3006] Human-Centered Task Analysis
[V2 4102] Functional Anthropometric Accommodation
[V2 5007] Cognitive Workload
[V2 7083] Cleaning Materials
[V2 9009] Sharp Corners and Edges – Fixed
[V2 9011] Sharp Corners and Edges - Loose
[V2 9012] Burrs
[V2 9024] Fluid/Gas Release
[V2 9027] Protection
[V2 10200] Physical Workload
[V2 11013] Suited Body Waste Management – Provision
[V2 11024] Ability to Work in Suits
[V2 11028] EVA Suit Urine Collection
[V2 11031] Suited Relative Humidity
[V2 11033] Suited Thermal Control
[V2 11034] Suited Atmospheric Data Recording
[V2 11035] Suited Atmospheric Data Displaying
[V2 11036] Suited Atmospheric Monitoring and Alerting
[V2 11037] EVA Suited Metabolic Rate Measurement
[V2 11038] EVA Suited Metabolic Rate Display
[V2 11039] Nominal Spacesuit Carbon Dioxide Levels



Risks

Due to the nature of the activities performed during EVAs, mishaps that occur over the course of an EVA pose a number of unique risks to the hardware, the crew, and the mission. Damage to the hardware might be as simple as a cracked casing or a lost wrench, or it could be as serious as a punctured suit that could lead to a fatal decompression. The crew experiences—or risks experiencing—injuries that range from minor to deadly. Missions have reported everything from bumps and contusions to more serious burns, exhaustion, and suffocation. A large number of mishaps also prevent mission objectives from being completed, either from hardware failures or crew injury. In extreme cases, the whole mission may have to be abandoned.

Hardware Failures

When hardware doesn't function as intended, an astronaut is forced to improvise (which may increase risk of injury) or abandon the task.

Voskhod 2: During the first spacewalk, cosmonaut Aleskei Lenov's suit ballooned, impeding maneuverability and ingress. He eventually had to let out some air from his suit to gain enough flexibility to re-enter the crew capsule. In addition, the workload of the spacewalk exceeded the ability of the suit's cooling system to maintain temperature. By the end of the EVA the suit was filled to the knees with perspiration. ***Relevant Standards: NASA-STD-3001 Volume 2 Rev C [V2 11024] Ability to Work in Suits, [V2 11037] Suited Metabolic Rate Measurement, [V2 11038] Suited Metabolic Rate Display***

STS-136/137: In both missions, an astronaut experienced unsafe elevated CO_2 levels during EVA when the EMU's CO_2 scrubbers stopped working adequately. In both cases the EVAs were terminated early. ***Relevant Standards: NASA-STD-3001 Volume 2 Rev C [V2 11034 Suited Atmospheric Data Recording], [V2 11035] Suited Atmospheric Data Displaying, [V2 11036] Suited Atmospheric Monitoring and Alerting, [V2 11039] Nominal Spacesuit Carbon Dioxide Levels***

STS-121 SAFER latch taped with Kapton tape

Common Issues
- Elevated CO_2 levels
- Helmet fogging
- Heating/cooling system failures
- Equipment coming unlatched

Aleksei Leonov's training suit and Voskhod 2 airlock

Skylab 2: Primary EVA heat exchangers suffered minor clogging during an EVA. A redesign was implemented, but there have been numerous issues with the heating & cooling systems that cause helmet fogging and pose health risks to the crew. ***Relevant Standards: NASA-STD-3001 Volume 2 Rev C [V2 11031] Suited Relative Humidity, [V2 11035] Suited Atmospheric Data Displaying, [V2 11036] Suited Atmospheric Monitoring and Alerting***

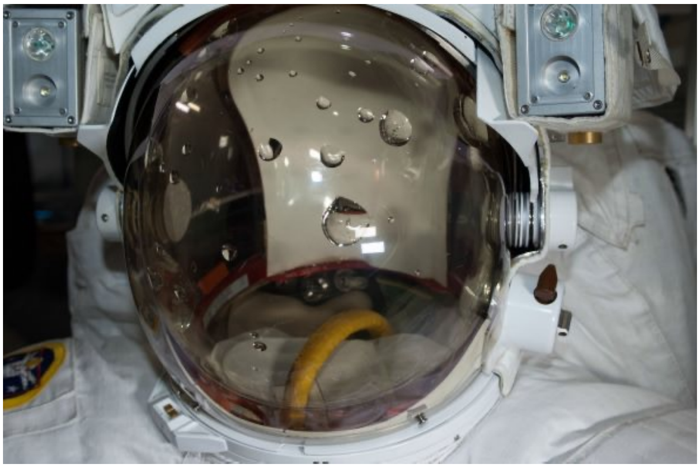
STS-121: The latches on a Simplified Aid For EVA Rescue (SAFER) became detached, putting an astronaut at an increased risk of drifting away from the shuttle. EVA tasks were postponed until the astronaut could be re-secured. The SAFER was later fixed using Kapton tape. ***Relevant Standard: NASA-STD-3001 Volume 2 Rev C [V2 9027] Protection***

Substances Present in Suit

While this type of mishap is usually the result of a hardware failure, it happens frequently enough that it falls into its own subcategory. It often causes discomfort or irritation, and sufficient quantities of loose fluids in an astronaut's helmet puts them at risk of suffocation or drowning.

Common Issues:
- Water
- Anti-fog agents
- Ammonia
- Urine

ISS-36: An hour into EVA 3, a large amount of water had collected in astronaut Luca Parmitano's suit and helmet. He was unable to complete his to-do list, had impaired visibility, and ran the risk of suffocating. The EVA was terminated early and he was assisted back into the airlock. Water intrusion is a common occurrence among EVA mishaps. ***Relevant standard: NASA-STD-3001 Volume 2 Rev C [V2 9024] Fluid/Gas Release***



Water inside Luca Parmitano's helmet

STS-100: An astronaut experienced severe eye irritation during the spacewalk due to the anti-fog solution used to polish his spacesuit visor. ***Relevant standard: NASA-STD-3001 Volume 2 Rev C [V2 7083] Cleaning Materials***

STS-130/ISS-24: Astronauts were exposed to ammonia from a leaking quick-disconnect fixture in the EMU. ***Relevant standard: NASA-STD-3001 Volume 2 Rev C [V2 9024] Fluid/Gas Release***

Urine Collection Device (female)

STS-41-C: The urine containment system in the EMU failed and caused discomfort to the astronaut, but the EVA was not terminated early. ***Relevant standards: NASA-STD-3001 Volume 2 Rev C [V2 9024] Fluid/Gas Release, [V2 11013] Suited Body Waste Management—Provision, [V2 11028] EVA Suit Urine Collection***

Urine Collection Device (male)

Hardware Damage

Similar to hardware failure, hardware *damage* results in an inability to use equipment, and exposes the crew to increased risk. Damage to the suit is particularly concerning; in the past even minor punctures have resulted in early EVA terminations.

Common Issues:
- Wear and tear
- Suit punctures

Example Events

Gemini 9: Over the course of his spacewalk, Gene Cernan's EVA suit became frayed and torn in spots along his back. As a result, he experienced painful heat exposure and suffered burns. Additionally, the workload required by the EVA overloaded the suit's cooling system; Cernan became overheated and exhausted, and his visor completely fogged up. ***Relevant standards: NASA-STD-3001 Volume 2 Rev C [V2 9027] Protection, [V2 11031] Relative Suit Humidity, [V2 11037] Suited Metabolic Rate Measurement, [V2 11038] Suited Metabolic Rate Display***

Gene Cernan Gemini 9 EVA June 5, 1996

STS-37/118/125: At some point during each of these missions, an astronaut's glove was cut or punctured. These were likely caused by normal wear and tear, as well as handling equipment which may have had burrs or sharp edges. ***Relevant standards: NASA-STD-3001 Volume 2 Rev C [V2 9009] Sharp Corners and Edges—Fixed, [V2 9011] Sharp Corners and Edges—Loose, [V2 9012] Burrs, [V2 9027] Protection***

STS-118 glove damage leading to early ending of third EVA

Crew Actions/Operations

Even when all the hardware is intact and functioning correctly, actions taken by the crew or operational conditions of the mission can directly or indirectly increase the risk to an EVA. Mistakes are made by crew or support personnel, which can be exacerbated by external factors.

Common Issues:
- Hardware secured or configured improperly
- Fatigue (pre-EVA and during EVA)
- Injuries from repeated actions
- Exposure to extreme conditions

Salyut 6 PE-1: A cosmonaut's safety tether was not properly secured prior to his EVA. Although he was still connected to the Salyut via his umbilical, he was exposed to an increased risk of becoming detached and drifting away from the vehicle. ***Relevant standard: NASA-STD-3001 Volume 2 Rev C [V2 3006] Human-Centered Task Analysis***

Gemini 11: EVA 1 was terminated early due to astronaut fatigue. ***Relevant Standards: NASA-STD-3001 Volume 2 Rev C [V2 3006] Human-Centered Task Analysis, [V2 10200] Physical Workload, NASA-STD-3001 Volume 1 Rev B [V1 4014] Completion of Critical Tasks***

Hand injury due to inadequate performance of EVA glove

STS-37: Ground control recommended against EVAs on consecutive days due to concerns over crew fatigue and time constraints. ***Relevant Standards: NASA-STD-3001 Volume 2 Rev C [V2 3006] Human-Centered Task Analysis, [V2 5007] Cognitive Workload, [V2 10200] Physical Workload, NASA-STD-3001 Volume 1 Rev B [V1 4014] Completion of Critical Tasks***

Apollo 15: The tight gloves, combined with the stress of repeating certain actions, resulted in minor hand injuries to the crew. A number of other missions have reported this phenomenon. ***Relevant Standards: NASA-STD-3001 Volume 2 Rev C [V2 3006] Human-Centered Task Analysis, [V2 4102] Functional Anthropometric Accommodation***

STS-57/63: Crew members reported feeling extremely cold in their EMUs. This was partly due to EVA operations taking place in complete shadow. ***Relevant Standards: NASA-STD-3001 Volume 2 Rev C [V2 3006] Human-Centered Task Analysis, [V2 11033] Suited Thermal Control***

STS-57 EVA

Application Notes

While keeping in mind that tradeoffs must be balanced and 100% safety cannot be reasonably achieved, there are steps that can be taken with regards to hardware design and operations structure that can mitigate risk and address common issues. Bear in mind that any recommendation has to be considered alongside other requirements imposed by the program (cost, weight, etc.).

Adding redundant features to hardware systems ensures that crew can continue using them even if one element fails or breaks. If there's a particular tool or piece of equipment that sees repeated use, it can be reinforced to withstand the extra stress. Lessons can be learned both from systems that fail regularly (are there common errors?) and resilient ones (why are they reliable?).

Mission operations can be designed to give crewmembers an advantage during EVAs. Scheduling mission operations with workload taken into consideration (before and during EVA) will reduce the risk of both human and hardware error. To that effect, other mission objectives must be taken into consideration when planning EVAs. Scheduling EVAs during favorable environmental conditions (low SPE activity, ample sunlight) helps astronauts work safely and effectively. Rigorous training can prepare crew for contingencies and reduce unfamiliar situations.

Back-Up

Major Changes Between Revisions

Original → Rev A

- Updated information to be consistent with NASA-STD-3001 Volume 1 Rev B and Volume 2 Rev C.

Referenced Standards

NASA-STD-3001 Volume 1 Revision B

[V1 4014] Completion of Critical Tasks The planned number of hours for completion of critical tasks and events, workday, and planned sleep period shall have established limits to assure continued crew health and safety.

NASA-STD-3001 Volume 2 Revision C

[V2 3006] Human-Centered Task Analysis Each human space flight program or project shall perform a human-centered task analysis to support systems and operations design.

[V2 4102] Functional Anthropometric Accommodation The system shall ensure the range of potential crewmembers can fit, reach, view, and operate the human systems interfaces by accommodating crewmembers with the anthropometric dimensions and ranges of motion as defined in data sets in Appendix F, Physical Characteristics and Capabilities, Sections F.2 and F.3.

[V2 5007] Cognitive Workload The system shall provide crew interfaces that result in Bedford Workload Scale ratings of 3 or less for nominal tasks and 6 or less for off-nominal tasks.

[V2 7083] Cleaning Materials The system shall provide cleaning materials that are effective, safe for human use, and compatible with system water reclamation, air revitalization, waste management systems, and spacesuits.

[V2 9009] Sharp Corners and Edges – Fixed Corners and edges of fixed and handheld equipment to which the bare skin of the crew could be exposed shall be rounded as specified in Table 18, Corners and Edges.

[V2 9011] Sharp Corners and Edges – Loose Corners and edges of loose equipment to which the crew could be exposed shall be rounded to radii no less than those given in Table 19, Loose Equipment Corners and Edges.

[V2 9012] Burrs Exposed surfaces shall be free of burrs.

[V2 9024] Fluid/Gas Release Hardware and equipment shall not release stored fluids or gases in a manner that causes injury to the crew.

[V2 9027] Protection Systems, hardware, and equipment shall be protected from and be capable of withstanding forces imposed intentionally or unintentionally by the crew.

[V2 10200] Physical Workload The system shall provide crew interfaces that result in a Borg-CR10 rating of perceived exertion (RPE) of 4 (somewhat strong) or less.

[V2 11013] Suited Body Waste Management – Provision Suits shall provide for management of urine, feces, menses, and vomitus of suited crewmembers.

[V2 11024] Ability to Work in Suits Suits shall provide mobility, dexterity, and tactility to enable the crewmember to accomplish suited tasks within acceptable physical workload and fatigue limits while minimizing the risk of injury.

[V2 11028] EVA Suit Urine Collection EVA suits shall be capable of collecting a total urine volume of $V_u = 0.5 + 2.24t/24$ L, where t is suited duration in hours.

[V2 11031] Suited Relative Humidity For suited operations, the system shall limit RH to the levels in Table 34, Average Relative Humidity Exposure Limits for Suited Operations.

Referenced Standards

[V2 11033] Suited Thermal Control The suit shall allow the suited crewmembers and remote operators to adjust the suit thermal control system.

[V2 11034] Suited Atmospheric Data Recording Systems shall automatically record suit pressure, ppO_2, and $ppCO_2$.

[V2 11035] Suited Atmospheric Data Displaying Suits shall display suit pressure, ppO_2, and $ppCO_2$ data to the suited crewmember.

[V2 11036] Suited Atmospheric Monitoring and Alerting Suits shall monitor suit pressure, ppO_2, and $ppCO_2$ and alert the crewmember when they are outside safe limits.

[V2 11037] EVA Suited Metabolic Rate Measurement The system shall measure or calculate metabolic rates of suited EVA crewmembers.

[V2 11038] EVA Suited Metabolic Rate Display The system shall display metabolic data of suited EVA crewmembers to the crew.

[V2 11039] Nominal Spacesuit Carbon Dioxide Levels The spacesuit shall limit the inspired CO_2 partial pressure (P_ICO_2) in accordance with Table 35, Spacesuit Inspired Partial Pressure of CO_2 (P_ICO_2) Limits.

Reference List

1. Gernhardt, M.L, Jones, J.A., Scheuring, R.A., Abercromby, A.F., Tuxhorn, J.A., & Norcross, J.R. Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems. *Human Health and Performance Risks of Space Exploration Missions.* *https://humanresearchroadmap.nasa.gov/evidence/reports/eva%20suit.pdf*
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3. Significant Incidents & Close Calls in Human Spaceflight. *JSC SMA Flight Safety Office*. https://sma.nasa.gov/SignificantIncidents/
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